International Journal of Emergency Medicine

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Quantitative effects of mechanical cardiopulmonary resuscitation devices in rural American emergency medical services: a retrospective cohort study

Peter H. King[1] and Esmaeil Bahalkeh[2*]

Abstract

Background Emergency medical service agencies increasingly utilize medical devices which perform external chest compressions during cardiac arrest. Due to the unique staffing and budget considerations of the rural emergency medical services environment, an investigation of mechanical cardiopulmonary resuscitation in this setting is warranted. Studying the effects of new technologies in the rural environment promotes improvement of the standard of rural prehospital care. This study evaluated the effect of mechanical cardiopulmonary resuscitation use on rural out-of-hospital cardiac arrest performance measures.

Methods Five hundred eighty-five rural cardiac arrests were assessed from National Emergency Medical Services Information System 2017–2019 data. Using both linear and logistic multivariate regression analysis, the effect of mechanical cardiopulmonary resuscitation on the incidence of a return of spontaneous circulation, the first defibrillation interval, and the first cardiac epinephrine administration interval was assessed.

Results In rural cardiac arrest with initial presentation of a shockable rhythm, the use of mechanical cardiopulmonary resuscitation devices delayed initial defibrillation by 21.5% ($p < 0.05$). A 15.1% ($p < 0.05$) delay in first administration of epinephrine was also found when mechanical cardiopulmonary resuscitation was used. Incidence of return of spontaneous circulation was unchanged between manual and mechanical cardiopulmonary resuscitation conditions.

Conclusions Current rural mechanical cardiopulmonary resuscitation device use can have a negative effect on prompt delivery of vital interventions. Our findings suggest that improvements to equipment training may help remedy improper utilization of mechanical cardiopulmonary resuscitation devices. Delaying application of mechanical cardiopulmonary resuscitation devices until time-sensitive interventions are complete may result in a better standard of care. Proper use of mechanical cardiopulmonary resuscitation devices may help to overcome inherent difficulties faced by rural prehospital clinicians.

Keywords Mechanical CPR, Prehospital, Resuscitation, Cardiac arrest

*Correspondence:
Esmaeil Bahalkeh
Esmaeil.Bahalkeh@unh.edu
[1]Biomedical Science, College of Life Sciences and Agriculture, University of New Hampshire, Rudman Hall, 46 College Road G05, Durham, NH 03824, USA
[2]Health Management and Policy, College of Health and Human Services, University of New Hampshire, Hewitt Hall, 4 Library Way 321, Durham, NH 03824, USA

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Introduction

Out-of-hospital cardiac arrest (OHCA) is a medical emergency in which resuscitative and even post-resuscitative care may be administered by emergency medical services (EMS) personnel operating without the direct supervision of advanced care providers [1]. As prehospital procedures and protocols continue to evolve, a focus on efficient and evidence-based resuscitation remains a priority. The predominant modern mechanical cardiopulmonary resuscitation (CPR) devices were introduced in the early twenty-first century and have become increasingly common across EMS agencies [2, 3]. Use of mechanical CPR by EMS agencies increased more than fourfold between 2010 to 2016 with urban communities at the forefront of adopting the technology and rural communities being the least likely to carry the devices [4]. This disparity may be attributed to the known lack of sufficient funding for ambulance services in these rural communities, with a Rural Policy Research Institute panel finding "Rural ambulance agency payments inadequately cover standby and fixed costs [5]." This budget disparity may result in a slower adoption of new and beneficial technology in rural EMS. In these rural communities, a concerning trend of decreased cardiac arrest survivability has been found. It has been shown that patients suffering from OHCA in urban settings have a higher chance of survival, likely due to response intervals for EMS care [6, 7]. This finding supports the use of technology which may be beneficial to OHCA patient outcomes in the rural setting. A 2021 study showed no significant difference between the outcomes in patients receiving mechanical or manual CPR yet suggested that use of mechanical CPR may be beneficial in non-ideal prehospital situations such as those with "delayed EMS response times [8]." This study seeks to continue investigating the role of mechanical CPR in rural communities where non-ideal prehospital situations may be the norm.

The American rural EMS environment faces unique challenges which are not always shared by urban EMS agencies. Prolonged response intervals, staffing challenges, and funding shortages contribute to hurdles met by rural prehospital care providers [5, 9]. Prehospital cardiac arrest management is largely standardized under the American Heart Association's (AHA) CPR guidelines, with the National Registry of Emergency Medical Technicians (NREMT) basing cardiac arrest protocols on AHA recommendations [10]. Despite this standardization, rural agencies still struggle to maintain a level of success in cardiac arrest management similar to their urban counterparts [6]. Management of cardiac arrest is taxing on EMS unit staffing, often requiring additional personnel at the emergency scene. A recent study found that patient survivability was highest when there were 9 or more EMS personnel on scene [11]. Rural EMS leadership may not have access to the resources needed to supply these additional personnel. Decisions regarding budget allocations can have large, observable effects on the daily operations of EMS agencies and the care available to their patients. Mechanical CPR devices may be especially appealing to rural agency leadership based on their reported ability to perform high quality chest compressions without EMS clinician intervention. Logically, these devices could let rural EMS clinicians focus on skill based patient care responsibilities. As rural EMS agencies continue to seek out increased efficiency in prehospital patient care, it is important to understand the considerations for implementing mechanical CPR devices appropriately. The methods of this study seek to investigate the relationship between rural mechanical CPR use and quantitative performance measures in the OHCA patient to identify areas for improvement of care.

Methods

Nationwide deidentified patient data was obtained from the National Emergency Medical Services Information System (NEMSIS). The data obtained was in its publicly available form as provided by a formal request. The period of interest was the three year period of 2017 to 2019 to avoid changes in cardiac arrest management protocols beginning in 2020 during the COVID-19 pandemic [12].

The NEMSIS dataset was obtained during May of 2024. All data analysis was performed in RStudio [13]. A retrospective cohort design was used. Eligibility criteria was defined as rural cardiac arrest patients, with further classification based on current manufacturer recommendations for mechanical CPR devices. Specifically, adult patients with a suspected medical reason for cardiac arrest were selected. During data refinement, patients were included if they had experienced cardiac arrest prior to emergency medical services arrival and they were found by EMS to be in an initial cardiac rhythm which could be defibrillated (shockable rhythm). Patients who did not receive cardiac epinephrine were excluded as conclusions regarding the interval from patient contact to first cardiac epinephrine administration could not be drawn. The data was split into an intervention and non-intervention cohort based on the use of mechanical CPR. The inclusion criteria are described visually in Fig. 1.

The outcomes of interest are extrapolated from the current American Heart Association Advanced Cardiac Life Support guidelines [14]. This was chosen as the source for performance measures due the certification of American EMS clinicians in AHA standards. Current best practices described by the AHA include early defibrillation and early administration of cardiac epinephrine. The outcomes of interest specified in this study are whether return of spontaneous circulation (ROSC) occurred in

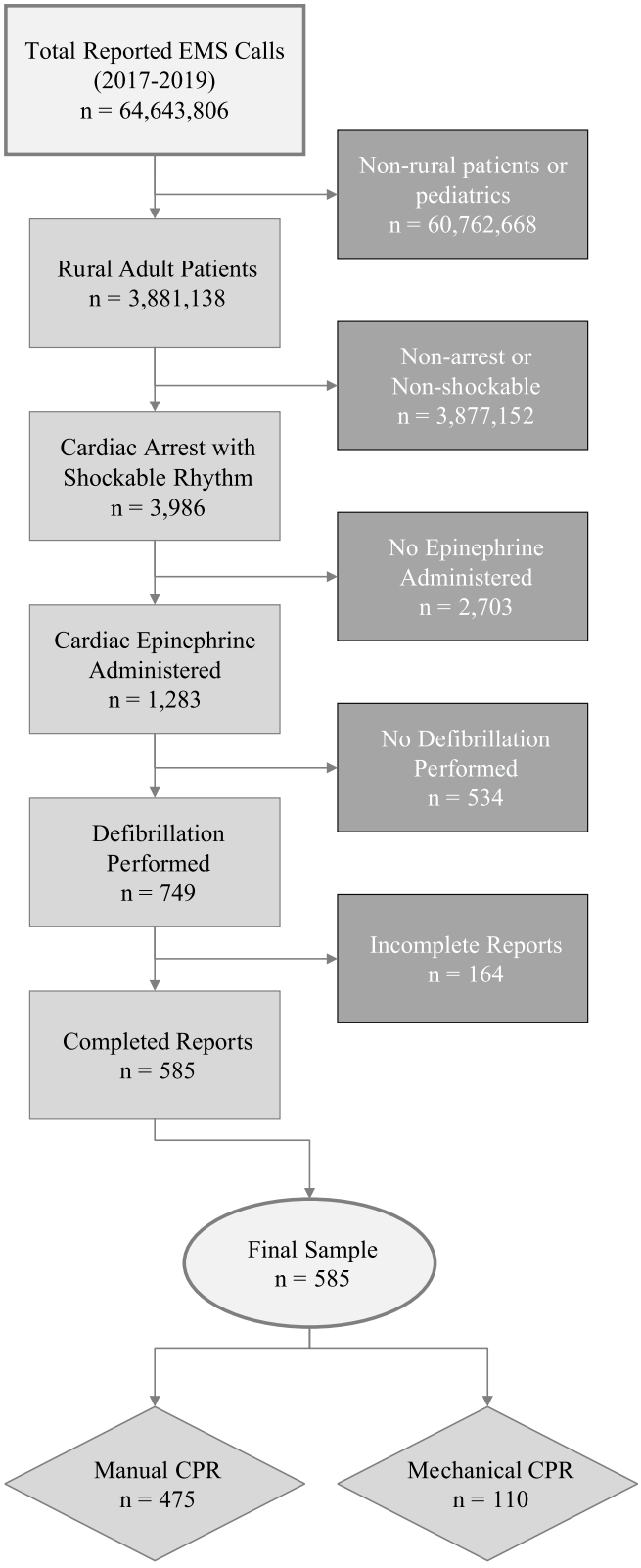

Fig. 1 Inclusion criteria outcomes

Table 1 Summary of the sample data

	Manual CPR (*N* = 475)	Mechanical CPR (*N* = 110)
Bystander CPR Provided	364 (76.6%)	78 (70.9%)
EMS Response time (minutes)	8.5 (6.3)	7.9 (6.1)
Age (years)	63.7 (13.4)	63.5 (13.0)
Sex		
Male	373 (78.5%)	85 (77.3%)
Female	102 (21.5%)	25 (22.7%)
Year		
2017	61 (12.8%)	19 (17.2%)
2018	153 (32.2%)	30 (27.2%)
2019	261 (54.9%)	61 (55.5%)
Census Division		
East North Central	70 (14.7%)	17 (15.4%)
East South Central	23 (4.8%)	2 (1.8%)
Middle Atlantic	2 (0.4%)	0
Mountain	70 (14.7%)	28 (25.5%)
New England	45 (9.5%)	0
Pacific	30 (6.3%)	1 (0.9%)
South Atlantic	84 (17.6%)	23 (20.9%)
West North Central	122 (25.7%)	34 (30.9%)
West South Central	29 (6.1%)	5 (4.5%)
Total Sample: *n* = 585		

any capacity during cardiac arrest management, the calculated interval from EMS patient contact to first defibrillation, and the interval from EMS patient contact to first cardiac epinephrine administration. ROSC incidence is utilized in this study as a measure of high quality CPR [15]. First cardiac epinephrine administration and defibrillation intervals were derived from time of patient contact and time of the procedure as recorded in the NEMSIS data. Cases with negative interval values were removed to ensure procedures were performed after EMS arrival. A skewed distribution was found for the derived intervals prompting a log transformation to create a normal distribution.

The independent variables specified for analysis were whether mechanical CPR was provided, whether bystander CPR occurred, EMS system response interval, age of patient, sex of patient, year of treatment, and US Census Division where care occurred. The Census Division was included as a control variable due to the large spread of included patients.

The normally distributed data created by the log transformation was then used for a two-sample t-test between the manual and mechanical CPR group on the outcomes of interest. A Chi-squared test was used to determine correlation between CPR type and whether ROSC occurred during patient care. A multivariate linear regression was performed to determine the effects of the recorded variables on the log transformation of the defibrillation and cardiac epinephrine administration intervals. An epinephrine interval regression was repeated on an all-rhythm sample that was not restricted by initial cardiac rhythm to determine if an effect on medication administration was found in both groups. A logistic regression was performed to determine the effects of recorded variables on the incidence of ROSC. Regression analysis was chosen due to its applicability in exploring variable relationships and frequent use in current medical research with datasets containing a wide range of healthcare considerations [16, 17].

Results

The inclusion criteria resulted in a sample size of 585 patients over the three years of interest. A summary of the sample data analyzed in the study can be found in Table 1. The distribution of mechanical and manual CPR in the years of interest is shown in Fig. 2. The Chi-squared test performed showed no significant difference between ROSC incidence in the manual and mechanical CPR groups. Two sample t-tests showed no significant difference in the log transformed procedure interval variables between the manual and mechanical CPR conditions.

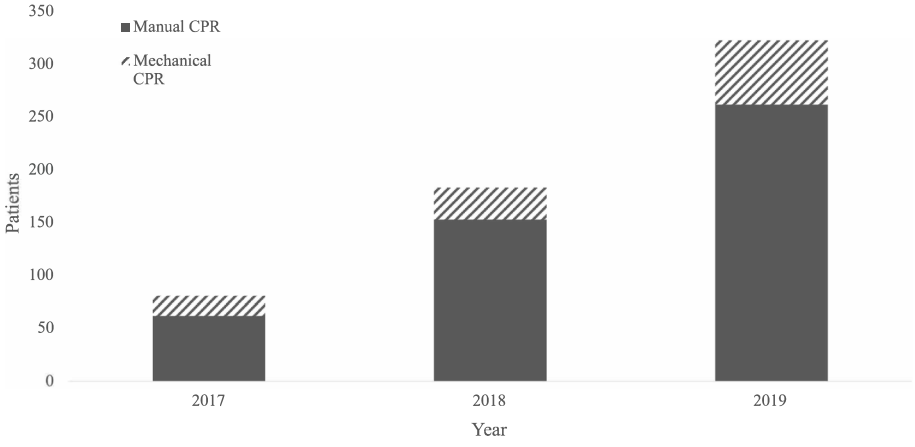

Fig. 2 Yearly prevalence of mechanical and manual CPR

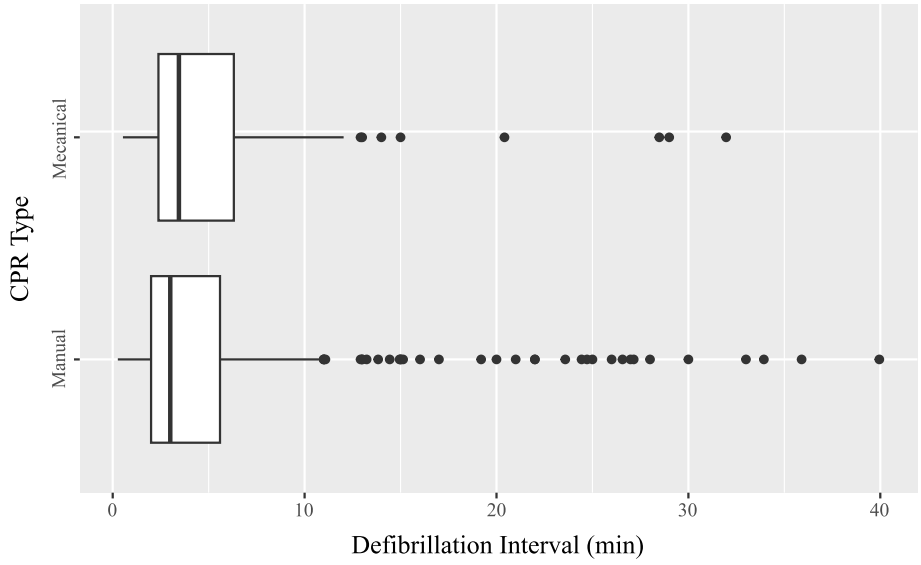

Fig. 3 Distribution of defibrillation interval in different CPR conditions

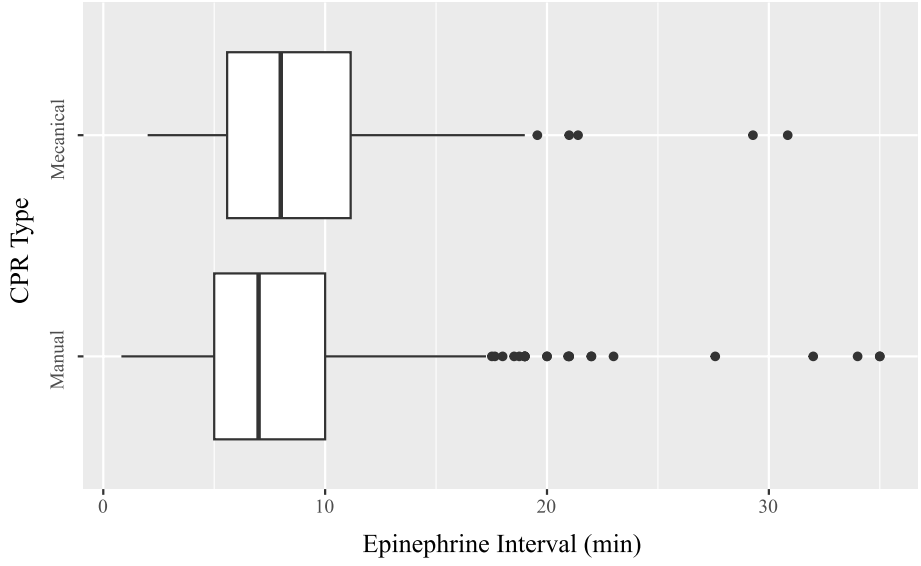

Fig. 4 Distribution of epinephrine administration interval in different CPR conditions

The initial skewed distribution in the epinephrine administration and defibrillation intervals is shown in Figs. 3 and 4.

Table 2 shows the results of the multivariate regressions. The shockable rhythm epinephrine interval linear regression shows a 15.1% increase in the interval of patient contact to first administration of cardiac epinephrine when mechanical CPR is used ($p < 0.05$). The shockable rhythm defibrillation interval linear regression also showed a 21.5% increase in the defibrillation interval under the mechanical CPR condition ($p < 0.05$). No change in ROSC frequency was noted between the conditions in the shockable rhythm logistic regression. The epinephrine interval linear regression performed in the all-rhythm condition did not replicate the increase in epinephrine interval.

Bystander CPR was shown to decrease the time to epinephrine administration by 16% in the all-rhythm sample ($p < 0.01$). In the shockable rhythm sample, bystander CPR was shown to decrease the first defibrillation interval by 17.9% ($p<0.05$). EMS response interval was found to have a negative correlation with ROSC incidence ($p < 0.01$) and a positive correlation to the defibrillation interval ($p < 0.05$). Male patients had a lower incidence of ROSC. The all-rhythm epinephrine interval linear regression analysis showed small discrepancies in the epinephrine interval between years.

Table 2 Results of multivariate regression models

	Dependent variable:			
	ROSC	**Defibrillation Interval (log)**	**Epinephrine Interval (log)**	
	(Shockable Rhythms)	**(Shockable Rhythms)**	**(Shockable Rhythms)**	**(All Rhythms)**
	logistic	***linear***	***linear***	***linear***
	(1)	**(2)**	**(3)**	**(4)**
Mechanical CPR Provided	0.104	0.215**	0.151**	0.015
	(0.226)	(0.092)	(0.059)	(0.032)
Bystander CPR Provided	0.309	−0.179**	−0.081	−0.160***
	(0.211)	(0.085)	(0.055)	(0.027)
EMS Response Interval (min)	−0.073***	0.015**	0.003	0.001
	(0.017)	(0.006)	(0.004)	(0.001)
Age	−0.009	0.001	0.0002	−0.0003
	(0.007)	(0.003)	(0.002)	(0.001)
Male	−0.508**	−0.117	−0.082	−0.047*
	(0.213)	(0.086)	(0.058)	(0.026)
2018	0.237	0.119	−0.087	0.094**
	(0.284)	(0.115)	(0.074)	(0.040)
2019	0.090	0.026	−0.084	−0.064*
	(0.268)	(0.108)	(0.070)	(0.037)
Census Division	*Included*	*Included*	*Included*	*Included*
Constant	0.523	1.301***	2.068***	2.126***
	(0.589)	(0.236)	(0.152)	(0.078)
Observations	585	585	585	4,640
Residual Std. Error		0.847 (df = 568)	0.546 (df = 568)	0.839 (df = 4623)
F Statistic		1.870*** (df = 16; 568)	2.590*** (df = 16; 568)	7.116*** (df = 16; 4623)
Log Likelihood	−372.670			
Akaike Inf. Crit	779.341			

*$p < 0.1$

**$p < 0.05$

***$p < 0.01$

Discussion

The findings of the analysis provide context to the best use of prehospital mechanical CPR and offer insight into how future improvements can be made to operating and training guidelines. The delay in crucial OHCA management interventions clarifies the priorities of EMS agencies using mechanical CPR devices. While mechanical CPR devices are often seen as a way to minimize EMS clinician fatigue or to improve CPR quality during patient extrication, prioritizing the placement of a mechanical CPR device over evidence-based, time sensitive interventions will result in delays to important care as noted in the findings above.

An ideal recommendation for mechanical CPR use would utilize current cardiac arrest management guidelines and manual chest compressions until application of mechanical CPR is safe, controlled, and feasible. The Maine Medical Direction and Practices Board (MDPB) has published a concise white paper detailing an outline of ideal mechanical CPR use for EMS agencies interested in adding a device to their practice [18]. The report focuses on maintaining CPR standards and initiating CPR manually. As these devices require cessation of manual CPR during device application, the paper advised applying the device piecewise during standard CPR pulse checks so that a prolonged pause in CPR would be avoided. The MDPB explicitly states that the addition of the "CPR device must not cause any additional or prolonged pauses in chest compressions [18]." Using mechanical CPR devices as a direct replacement for manual CPR is not the ideal application. Training with and using mechanical CPR devices as a secondary adjunct to proper manual CPR could help to reduce many of the shortcomings found in this study.

The relationship between bystander CPR and decreased defibrillation interval supports the idea that manual CPR as a first-line resuscitation measure may prevent delays in timely patient care. These delays may be worsened in areas where mechanical CPR is viewed as a direct replacement for manual CPR and is therefore prioritized

upon arrival at the patient. The presence of bystander CPR may prompt EMS personnel to delay mechanical CPR application and prepare for defibrillation or epinephrine administration immediately while assuming the role of chest compressions from the bystander. Specific information regarding bystander Automatic External Defibrillator (AED) application was not available, but the application of an AED prior to EMS arrival may also reduce the defibrillation interval due to the ability of EMS to utilize the AED applied on scene.

The epinephrine interval linear regression analysis performed on the all-rhythm sample did not replicate the delay in epinephrine administration during mechanical CPR which was noted in the shockable rhythm sample. A non-significant positive correlation remained. The all-rhythm sample had a significantly larger mean epinephrine interval, suggesting that initial cardiac rhythm presentation may affect the general sequence and approach to cardiac arrest treatment. While the shockable rhythm sample demonstrates a need for improvement in epinephrine interval in the mechanical CPR cohort, the larger all-rhythm sample shows a possibility for improvement across both cohorts.

Our analysis suggests that rural use of mechanical CPR does not significantly change ROSC incidence prehospitally, which may further support a delayed, supplemental application of these devices. Previous studies have presented similar findings of no significant difference in ROSC rates and care outcomes during and following hospital admission [8, 19]. Viewing mechanical CPR as an adjunct to OHCA management may facilitate a more evidence-based transition from manual and mechanical CPR as it becomes indicated in management of an emergency scene or patient. Chest compressions during extrication or transport to the hospital may be difficult to provide without risking poor compression technique [20, 21]. These instances may then be ideal applications for mechanical CPR, while the early period of OHCA management may benefit from manual CPR until the first time-sensitive interventions in the cardiac arrest care algorithm have been completed. Understanding specific EMS agency shortcomings in cardiac arrest management will also enable agency leadership to better reinforce care guidelines for mechanical CPR use. EMS agencies or regional leadership may seek to standardize care goals or provide guidelines similar to those published by the Maine Medical Direction and Practices Board [18].

Mechanical CPR devices may be especially attractive to EMS agencies with minimal or inconsistent staffing and prolonged transport intervals as are common in the rural EMS environment [9]. Further investigation into the effect of mechanical CPR use on these challenges is needed for conclusions to be drawn. Training targets can be set and routinely assessed even in agencies with intrinsic challenges to OHCA care. Regular training may be beneficial for EMS agencies with low incidence of mechanical CPR use as the effect of a single training may be short lived [22]. Improving the common agency understanding of OHCA care goals and priorities may provide a more seamless incorporation of mechanical CPR devices in patient care. Improving prolonged OHCA care while simultaneously improving early OHCA care goals should be achievable through training and unambiguous standard procedures regarding mechanical CPR.

The marked change in Fig. 1 between the full sample size of EMS activations meets expectations for presumed incidence of cases of interest. A notable difference was found between rural EMS activations as a percentage of total activations and expected percentage based on American population distribution. As NEMSIS data is a convenience sample based on reporting by local agencies, a known shortcoming of the data is the lack of reporting from agencies without the resources needed to maintain and report records to the NEMSIS standard [23]. As previously explored, rural EMS agencies may lack funding which would better position them to have reportable data. As data reporting continues to become more accessible, rural EMS agencies may be able to contribute data more easily and future studies will benefit from the resulting larger sample size.

The COVID-19 pandemic may have changed how many states or municipalities manage OHCA [12], processing of data since the start of the pandemic will likely need to be adjusted based on the most current standards of OHCA management and COVID-19 considerations. An analysis of changes to OHCA management and the reversion to general precautions may assist with understanding what considerations should be taken with the data since the start of the COVID-19 pandemic.

There are implicit limitations in this study to note. Data obtained from NEMSIS is compiled from patient care reports completed by EMS clinicians from across America, making verification of reported times and findings not possible. This study was performed based on the assumption of accurate documented findings of these EMS clinicians. Additionally, as the data obtained is a convenience sample, selection of agencies with adequate resources for data reporting may have occurred. The analysis in the study is limited by the available variables, and there is no explicitly documented time of mechanical CPR application in the dataset utilized. As a result, it is unknown whether some of the treated patients received manual CPR prior to mechanical and therefore have delays unrelated to their CPR type and application order. This study did not explicitly investigate patient outcomes, and to effectively do so would require patient outcome reporting from admitting hospitals. These metrics are not as readily available as the EMS data provided.

Further investigation is warranted to observe the effects on patient outcomes in rural communities. Future studies may seek to continue investigating the trends noted here to determine whether increased mechanical CPR prevalence further effects performance measures. Apart from the considerations of the COVID-19 pandemic as noted above, future studies may benefit from incorporating training or funding data to more definitively determine mediating variables. Regional or state EMS systems with a significant rural population may be interested in investigating their own capabilities. Local research may also provide more actionable suggestions for improving agency training and compliance.

Conclusions

As mechanical CPR implementation in rural EMS continues its current trend of growth, it will be important to ensure that the devices are being used in accordance with best practices of OHCA management. A concise and specific use guide should be utilized at the local level so that rural EMS agencies adopting mechanical CPR have unambiguous care goals with associated ideal timelines. Manual CPR and cardiac arrest management interventions should not be initially delayed or withheld in favor of mechanical CPR. EMS Medical Direction boards at the state or regional level may implement explicit guidelines for EMS agencies interested in incorporating mechanical CPR in their patient care. Rural EMS agencies with data sharing and analysis capabilities may benefit from observing trends in their own application of mechanical CPR to address possible shortcomings in real time. This study's findings should continue to be monitored for future trends as the number of rural communities utilizing mechanical CPR continues to increase.

Authors' contributions

PK acquired data, performed data processing and statistical analysis, created accompanying figures, and wrote the final manuscript. EB provided advising, created the study methods, and provided feedback and editing for the final manuscript.

Funding

This study was funded by the University of New Hampshire Hamel Center for Undergraduate Research. The Hamel Center had no influence on conceptualization, design, data collection, analysis, decision to publish, or preparation of the manuscript.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Unconditional approval of the protocol by the University of New Hampshire Institutional Review Board for the Protection of Human Subjects in Research was obtained prior to obtaining data.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 25 February 2025 / Accepted: 11 June 2025
Published online: 11 August 2025

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